output as high as 120 mW.

The concentration of Mg used to dope the first p-type cladding layer **14** is preferably adjusted to about 5×10^{16} cm^{-3} to 1×10^{18} cm^{-3}. If the concentration of Mg is lower than 5×10^{16} cm^{-3}, a sufficiently high potential barrier cannot be provided against electrons in the first p-type cladding layer **14** so that the electrons injected from the n-side electrode overflow from the active layer **13** to the first p-type cladding layer **14**. If the concentration of Mg is higher than 1×10^{18} cm^{-3}, on the other hand, Mg is diffused from the first p-type cladding layer **14** to the active layer **13** to degrade the crystalline quality of the active layer **13**. This may degrade the reliability of the semiconductor laser device.

Thus, in the semiconductor laser device according to the first embodiment, the first p-type cladding layer **14** is formed to have a relatively high resistance so that the diffusion of the current is less likely to occur in the first cladding layer. This reduces the threshold current and operating current of the semiconductor laser device, improves the temperature characteristic thereof, and allows a high-output operation thereof.

Although the first embodiment has used magnesium to dope the first p-type cladding layer **14** and zinc to dope the second p-type cladding layer **16**, impurities used in the first and second cladding layers **14** and **16** may come in any combination provided that the carrier scattering effect is relatively large in the first p-type cladding layer **14** and relatively small in the second cladding layer **16**.

The first p-type cladding layer **14** need not necessarily be doped with Mg over the entire direction of thickness thereof. It is also possible to dope the lower portion of the first p-type cladding layer **14** with Mg and dope the upper portion thereof with Zn. In the arrangement also, a current is diffused in the upper portion of the first p-type cladding layer **14** but the diffusion of the current is suppressed successfully in the lower portion thereof. Compared with the case where the first p-type cladding layer **14** is doped only

with magnesium over the entire direction of thickness thereof, therefore, the current at a high density is injected into the active layer **13**.

In the first embodiment, a substrate made of p-type GaAs may also be used in place of the n-type substrate **11**.

Although the first embodiment has adjusted the composition of In to about 0.5 in each of the semiconductor layers made of AlGaInP to achieve lattice matching between the semiconductor layer and the n-type substrate **11**, it is sufficient for the composition of In to be in a range not less than 0.45 and not more than 0.55. The arrangement allows each of the semiconductor layers made of AlGaInP to be formed such that lattice matching is achieved in the semiconductor layer and GaAs composing the n-type substrate **11**.

It is also possible to form a complex refraction index waveguide structure by using GaAs instead of AlInP as a material composing the first current blocking layer **18**.

The active layer **13** is not limited to the structure using the multiple quantum well layer **13a**. The active layer **13** may be an active layer having a single quantum well structure in which only one well layer made of GaInP is formed or a bulk active layer having a single structure.

-Fabrication Method of EMBODIMENT 1-

A method for fabricating the semiconductor laser device according to the first embodiment will be described with reference to the drawings.

FIGS. **4A** and **4B** and FIGS. **5A** and **5B** show cross-sectional structures of the semiconductor laser device according to the first embodiment in the individual process steps of the fabrication method therefor. The description of the components shown in FIGS. **4A** and **4B** and FIGS. **5A** and **5B** which are the same as shown in FIG. **1** will be omitted by retaining the same reference numerals.

First, as shown in FIG. **4A**, the n-type cladding layer **12**, the active layer **13**, the

first p-type cladding layer **14**, the etching stopper layer **15**, a second-p-type-cladding layer forming layer **16A**, a first-contact-layer forming layer **17A**, and a cap layer **31** made of GaAs are grown successively on the n-type substrate **11** by, e.g., metal organic chemical vapor deposition (MOCVD). The cap layer **31** prevents the surface of the first-contact-layer forming layer **17A** from being oxidized during a period of transition to the subsequent photolithographic step.

In the step of forming each of the semiconductor layers by MOCVD, each of triethylgallium (TEG), trimethylaluminum (TMA), and trimethylindium (TMI) is used as a source for a group III compound and each of phosphin (PH_3) and arsine (AsH_3) is used as a source for a group V compound. By using hydrogen as a carrier gas, these sources are introduced into a reaction vessel made of quartz. Under the conditions under which the inner pressure of the reaction vessel is about 1.0×10^4 Pa (about 76 Torr) and the substrate temperature is about 750 °C, the individual semiconductor layers are deposited successively by crystal growth by properly switching the source being supplied and the amount of the source being supplied. By introducing, e.g., dimethylzinc ($Zn(CH_3)_2$) or biscyclopentadienyl magnesium ($(C_5H_5)_2Mg$) as a source for a p-type impurity during the crystal growth of each of the semiconductor layers, each of the semiconductor layers can be doped with a desired p-type impurity.

Next, as shown in FIG. **4B**, the cap layer **31** is etched away and then a silicon oxide film for forming a mask pattern is formed on the first-contact-layer forming layer **17A** by CVD. The formed silicon oxide film is patterned by photolithography and dry etching to form a striped mask pattern **32**.

Next, as shown in FIG. **5A**, the first-contact-layer forming layer **17A** and the second-p-type-cladding layer forming layer **16A** are selectively removed in succession by etching using the mask pattern **32** so that the ridge-shaped second p-type cladding layer **16**

is formed from the second-p-type-cladding layer forming layer **16A** and the first contact layer **17** covering the upper surface of the second p-type cladding layer **16** is formed from the first-contact-layer forming layer **17A**.

As an etchant for the first contact layer **17**, a hydrochloric-acid-based etchant, e.g., may be used appropriately. Selective etching of the second p-type cladding layer **16** can be performed by using an etchant having a high etching selectivity of AlGaInP to GaInP, such as a sulfuric-acid-based etchant, so that the etching stopper layer **15** as the underlying layer is hardly etched. This allows the second p-type cladding layer **16** to be formed into a ridge-shaped configuration.

Next, as shown in **FIG. 5B**, the first and second current blocking layers **18** and **19** are deposited successively by crystal growth on the etching stopper layer **15** in such a manner as to cover the respective side surfaces of the second p-type cladding layer **16** and the first contact layer **17** and the upper surface of the mask pattern **32**. Then, a lift-off process is performed with respect to the mask pattern **32** to remove the respective portions of the first and second current blocking layers **18** and **19** overlying the mask pattern **32** simultaneously with the mask pattern **32**, thereby exposing the first contact layer **17**.

Thereafter, the second contact layer **20** is deposited by crystal growth over the first contact layer **17** and the second current blocking layer **19**. Subsequently, a metal material is vapor deposited on the lower side of the n-type substrate **11** by, e.g., electron beam vapor deposition to form the n-side electrode **21**. Likewise, a metal material is vapor deposited on the upper side of the second contact layer **20** to form the p-type electrode **22**, whereby the semiconductor laser device according to the first embodiment shown in **FIG. 1** is completed.

The method for fabricating the semiconductor laser device according to the first embodiment is characterized by doping the first and second p-type cladding layers **14** and

16 with different impurities such that the first p-type cladding layer 14 has a resistivity higher than that of the second p-type cladding layer 16. The first p-type cladding layer 14 is formed while it is doped with Mg. The second p-type cladding layer 16 is formed while it is doped with Zn.

A method for forming each of the semiconductor layers is not limited to MOCVD. Instead of MOCVD, molecular beam epitaxy (MBE) may also be used.

VARIATION 1 OF EMBODIMENT 1

A semiconductor laser device according to a first variation of the first embodiment will be described herein below.

The semiconductor laser device according to the first variation of the first embodiment has the same structure as the semiconductor laser device according to the first embodiment shown in FIG. 2, except that Mg is also used as a dopant for doping the first p-type cladding layer 14 in addition to Zn. The compound composition and film thickness of each of the semiconductor layers are the same as those shown in Table 1. The dopant and doping concentration in each of the semiconductor layers other than the first p-type cladding layer 14 are the same as those shown in Table 1. A description will be given herein below to the difference between the first variation and the first embodiment.

The semiconductor laser device according to the first variation of the first embodiment is different from the first embodiment in that Zn is also used as a third impurity to dope the first p-type cladding layer 14 in addition to Mg. The first p-type cladding layer 14 is doped with Zn and Mg such that the total concentration of Zn and Mg as the p-type impurities is about 1×10^{18} cm^{-3}, i.e., that the mixture ratio between Zn and Mg is 1:1.

When an AlGaInP-based semiconductor is doped with Mg and Zn at a mixture ratio of 1:1, the mobility in the AlGaInP layer is slightly higher than in the case where only

Mg having a large carrier scattering effect is used to dope the AlGaInP layer. This is because, if a plurality of impurities are present in a semiconductor material, the scattering of carriers is greatly influenced by the concentration of a dopant species having a relatively large carrier scattering effect. Therefore, it may be said that, if Zn and Mg are used as p-type dopants for doping a semiconductor made of AlGaInP, the carrier scattering effect is substantially determined by the concentration of Mg. Consequently, the resistivity of the first p-type cladding layer **14** has nearly the same value as in the case where Mg at a concentration of about 5 x 10^{17} cm^{-3} is used to dope the first p-type cladding layer **14**.

By doping the first p-type cladding layer **14** with Mg and Zn at a high concentration of about 1 x 10^{18} cm^{-3}, the potential barrier of the first p-type cladding layer **14** to the active layer is increased so that the overflow of electrons injected in the active layer **13** into the first p-type cladding layer **14** is suppressed effectively. Since the concentration of Zn is about 5 x 10^{17} cm^{-3}, the diffusion of the impurities into the active layer **13** is suppressed. In particular, Mg having a low diffusion coefficient is hardly diffused into the active layer **13**. Even if the doping concentration in the first p-type cladding layer **14** is increased to a value higher than in the first embodiment, therefore, the amounts of the impurities diffused into the active layer **13** are barely increased.

Thus, in the semiconductor laser device according to the first variation of the first embodiment, Zn as a dopant having a smaller carrier scattering effect than Mg is used to dope the first p-type cladding layer **14** in addition to Mg as a dopant having a relatively large carrier scattering effect. This provides a larger potential barrier against electrons in the active layer **13** than in the first embodiment, while retaining a high resistivity, and thereby improves the reliability of the semiconductor laser device.

In the first variation of the first embodiment, the mixture ratio between Mg and Zn used to dope the first p-type cladding layer **14** is not limited to 1:1. It is also possible to

increase the resistivity of the first p-type cladding layer **14** by increasing the ratio of Mg to Zn such that the diffusion of the current is further suppressed.

The total concentration of Mg and Zn as p-type impurities is preferably in a range not less than 1×10^{18} cm^{-3} and not more than 5×10^{18} cm^{-3}. If the total concentration of Mg and Zn as p-type impurities is adjusted to 1×10^{18} cm^{-3} or more, a larger effect of suppressing the overflow of electrons than in the first embodiment is achieved. If the total concentration of Mg and Zn as p-type impurities is adjusted to 5×10^{18} cm^{-3} or more, the p-type impurities are diffused from the first p-type cladding layer **14** into the active layer **13** so that the reliability of the semiconductor device is degraded.

In each of the first embodiment and the first variation thereof, the combination of impurities used to dope the first p-type cladding layer **14** is not limited to that of Mg and Zn. Any combination of impurities may be used provided that either of the impurities has a larger carrier scattering effect than the impurity used to dope the second p-type cladding layer **16**.

VARIATION 2 OF EMBODIMENT 1

A semiconductor laser device according to a second variation of the first embodiment will be described herein below with reference to the drawings.

FIG. **6** shows a cross-sectional structure of the semiconductor laser device according to the second variation of the first embodiment. The description of the components shown in FIG. **6** which are the same as those shown in FIG. **1** will be omitted by retaining the same reference numerals.

As shown in FIG. **6**, the n-type cladding layer **12**, the active layer **13** having a multiple quantum well structure, the first p-type cladding layer **14**, and the etching stopper layer **15** are deposited successively by crystal growth on the n-type substrate **11**. A current blocking layer **41** made of n-type $Al_{0.5}In_{0.5}P$ with a film thickness of about 0.3 μm and

formed with a stripe trench portion and a second p-type cladding layer **42** made of p-type $Al_{0.35}Ga_{0.15}In_{0.5}P$ with a film thickness of about 2 μm and having a lower portion thereof formed in a stripe configuration to fill the trench portion of the current blocking layer **41** from thereabove are formed on the etching stopper layer **15**. A first contact layer **43** and the second contact layer **20** each made of p-type $Ga_{0.5}In_{0.5}P$ with a film thickness of about 50 nm are stacked successively on the second p-type cladding layer **42**. The n-side electrode **21** is formed on the lower side of the n-type substrate **11**, while the p-type electrode **22** is formed on the upper side of the second contact layer **20**.

The semiconductor laser device according to the second variation of the first embodiment is formed as a semiconductor laser device having a so-called inner stripe waveguide structure in which a current blocking layer is formed in a cladding layer. With the application of a specified voltage between the n-side electrode **21** and the p-side electrode **22**, a current injected from the p-type electrode is confined by the current blocking layer **41** to reach the active layer **13** and cause radiative recombination so that laser beam oscillation at a wavelength of about 650 nm corresponding to the band gap of the well layer of the active layer **13** occurs.

In contrast to the first embodiment which has formed the second p-type cladding layer **16** into a ridge-shaped configuration so that the film thickness thereof is limited by the width of the upper ridge portion, the second variation of the first embodiment can increase the film thickness of the second p-type cladding layer **42** by forming the inner stripe waveguide structure. As a result, the distance between the active layer **13** and the second contact layer **20** can be increased so that an absorption loss resulting from the absorption of the laser beam oscillated from the active layer **13** by the second contact layer **20** made of GaAs is reduced.

Since the first p-type cladding layer **14** is doped with Mg at a concentration of

about 5 x 10^{17} cm^{-3} and the second p-type cladding layer **42** is doped with Zn at a concentration of about 1 x 10^{18} cm^{-3} in the semiconductor laser device according to the second variation of the first embodiment, the ineffective currents resulting from the diffusion of the currents in the first p-type cladding layer **14** can be reduced by increasing the resistivity of the first p-type cladding layer **14** and the series resistance of the semiconductor laser device can be reduced by increasing the doping concentration in the second p-type cladding layer **42**.

The second variation of the first embodiment is not limited to the structure using only Mg as the dopant for doping the first p-type cladding layer **14**. It is also possible to use Mg and Zn in combination. By doping the first p-type cladding layer **14** with Zn and Mg, it becomes possible to increase the potential barrier against electrons in the active layer **13**, while holding the resistivity of the first p-type cladding layer **14** high, so that the reliability of the semiconductor laser device is improved.

EMBODIMENT 2

The second embodiment of the present invention will be described herein below with reference to the drawings.

FIG. 7 shows a cross-sectional structure of the semiconductor laser device according to the second embodiment. The description of the components shown in FIG. 7 which are the same as shown in FIG. 1 will be omitted by retaining the same reference numerals.

As shown in FIG. 7, an n-type cladding layer **52** made of n-type $Al_{0.5}Ga_{0.5}As$ with a thickness of about 2.5 μm, an active layer **53** having a multiple quantum well structure, a first p-type cladding layer **54** made of p-type $Al_{0.5}Ga_{0.5}As$ with a film thickness of about 0.1 μm, an etching stopper layer **55** made of p-type $Al_{0.2}Ga_{0.8}As$ with a film thickness of about 10 nm, and a second p-type cladding layer **56** made of p-type $Al_{0.5}Ga_{0.5}As$ with a

film thickness of about 1 μm and formed into a ridge-shaped configuration are deposited successively by crystal growth on an n-type substrate **51** made of n-type GaAs with a thickness of about 100 μm. A current blocking layer **57** made of n-type $Al_{0.6}Ga_{0.4}As$ with a film thickness of about 0.7 μm is formed on the etching stopper layer **55** to cover the side surfaces of the second p-type cladding layer **56**. A contact layer **58** made of p-type GaAs with a thickness of about 3 μm is formed over the current blocking layer **57** and the second p-type cladding layer **56**.

An n-side electrode made of an alloy containing, e.g., Au, Ge, and Ni is formed on the lower side of the n-type substrate **51** to make ohmic contact therewith, while a p-side electrode made of an alloy containing, e.g., Cr, Pt, and Au is formed on the lower side of the n-type substrate **51** to make ohmic contact therewith.

The active layer **53** is composed of: a multiple quantum well layer **53a** consisting of well layers each made of undoped GaAs with a film thickness of about 3 nm and a barrier layer made of $Al_{0.3}Ga_{0.7}As$ with a film thickness of about 8 nm, which are alternately stacked; and upper and lower optical guide layers **53b** each made of $Al_{0.3}Ga_{0.7}As$ with a film thickness of about 20 nm and having the multiple quantum well layer **53a** interposed therebetween.

In the semiconductor laser device according to the second embodiment, the active layer **53** has a multiple quantum well structure having a band gap corresponding to a wavelength of 780 nm. If a current passing through the current blocking layer **57** has reached the active layer **53**, a laser beam at an oscillating wavelength of 780 nm is emitted therefrom.

Table **2** shows specific dopant species and doping concentrations in the individual layers of the semiconductor laser device thus constituted.

Table 2

Semiconductor Layer	Thickness	Compound Composition	Doping Conditions	
			Dopant	Concentration (cm^{-3})
Contact Layer	3 μm	GaAs	Zn	2×10^{19}
Current blocking layer	0.7μm	$Al_{0.6}Ga_{0.4}As$	Si	1×10^{18}
2nd p-Type Cladding layer	1 μm	$Al_{0.5}Ga_{0.5}As$	Zn	2×10^{18}
Etching Stopper Layer	10 nm	$Al_{0.2}Ga_{0.8}As$	Zn	1×10^{18}
1st p-Type Cladding layer	0.1μm	$Al_{0.5}Ga_{0.5}As$	C	1×10^{18}
Active Layer Quantum Well Layer Well Layers Barrier Layer Optical Guide Layers	 3 nm Each 8 nm 20 nm Each	 GaAs $Al_{0.3}Ga_{0.7}As$ $Al_{0.3}Ga_{0.7}As$	 — — —	 — — —
n-Type Cladding layer	2.5 μm	$Al_{0.5}Ga_{0.5}As$	Si	1×10^{18}
n-Type Substrate	100 μm	GaAs	Si	1×10^{18}

As shown in Table 2, the first p-type cladding layer 54 uses carbon (C) as a p-type dopant and each of the etching stopper layer 45, the second p-type cladding layer 56, and the contact layer 58 uses zinc (Zn) as a p-type dopant in the semiconductor laser device according to the second embodiment. The doping concentration in the first p-type cladding layer 54 is about 1×10^{18} cm^{-3}, while the doping concentration in the second p-type cladding layer 56 is about 2×10^{18} cm^{-3}. As an n-type dopant, silicon (Si) at a concentration of about 1×10^{18} cm^{-3} is used.

The second embodiment is characterized in that carbon is used as the dopant (first impurity) for doping the first p-type cladding layer 54 and Zn is used as the dopant (second impurity) for doping the second cladding layer 56. Consequently, the resistivity of the first p-type cladding layer 54 becomes higher than that of the second p-type cladding layer 56 so that sidewise ineffective currents flowing in the first p-type cladding layer 54 are reduced without increasing the series resistance of the semiconductor laser device. This is because, if a comparison is made between the respective cases where an AlGaAs-based semiconductor is doped with carbon and zinc, carbon gives greater influence than zinc on the mobility of carriers in the semiconductor.

Accordingly, the carriers injected into the first p-type cladding layer 54 becomes less likely to be diffused therein, in the same manner as in the first embodiment, so that a current is injected efficiently in the active layer 53, while the resistivity of the second p-type cladding layer 56 can be reduced by doping the second p-type cladding layer 56 to a high concentration of 2×10^{18} cm^{-3}. This reduces the threshold current and operating current of the semiconductor device and provides a high-output semiconductor device.

If Mg is used as a p-type impurity in an AlGaAs-based semiconductor, a problem termed delayed doping in which the semiconductor is not doped with Mg even after the supply of a source for Mg is initiated or a problem termed memory effect in which the

semiconductor is doped continuously with Mg even after the supply of the source for Mg is halted occurs so that a specified doping concentration is not obtained. Therefore, the second embodiment has not used Mg as a p-type impurity.

The second embodiment is not limited to the structure using only carbon as a p-type impurity for doping the first p-type cladding layer 54. In addition to carbon, Zn may also be used as a third impurity. The arrangement increases the impurity concentration in the first p-type cladding layer 54, while keeping the resistivity thereof relatively high, so that the overflow of electrons from the active layer 53 into the first p-type cladding layer 54 is prevented effectively.

The second embodiment is not also limited to the structure having a ridge stripe waveguide in which the second p-type cladding layer 56 is formed into a ridge-shaped configuration on the first p-type cladding layer. The second embodiment may also assume a structure having an inner stripe waveguide. Specifically, a current blocking layer having a stripe trench portion is formed on the first cladding layer 54 and the second p-type cladding layer 56 is formed appropriately to have a stripe lower portion for filling up the trench portion in the current blocking layer.